Comment on the article "UCN anomalous losses and the UCN capture cross section on material defects" by A. Serebrov et al.

A.L. Barabanov [a] and K.V. Protasov [b]

[a] *Kurchatov Institute, 1, Kurchatov square, Moscow 123182, Russia*

[b] *Laboratoire de Physique Subatomique et de Cosmologie, IN2P3-CNRS, UJFG, 53, Avenue des Martyrs, F-38026 Grenoble Cedex, France*

Abstract

We present correct solution of the problem about a scattering of the neutron on a point-like defect existing in a medium and show that this mechanism cannot explain anomalous losses of UCN in storage bottles.

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In a recent article by Serebrov et al. [1], a possible explanation of the problem of anomalous losses of UCN by scattering on the defects was proposed. Unfortunately this explanation is based on a wrong solution to the quantum mechanical scattering problem and thus cannot be considered as a credible hypothesis.

Serebrov et al. consider the problem on the scattering of neutrons on a point-like defect existing in a medium. Following the article [1], the medium bulk is described by usual Fermi potential

$$V_1(\mathbf{r}) = \begin{cases} U - iW, & z > 0, \\ 0, & z < 0. \end{cases} \tag{1}$$

The point-like defect situated at $\mathbf{r}_0$ ($\mathbf{r}_0 = (0, 0, z_0)$ with $z_0 \geq 0$; $z_0 = 0$ corresponding to the particular case of a defect on the surface of the medium)

Email addresses: barab@mbslab.kiae.ru (A.L. Barabanov), protasov@lpsc.in2p3.fr (K.V. Protasov).

is described by a potential

$$V_2 = \frac{2\pi\hbar^2 B}{m}\delta(\mathbf{r} - \mathbf{r}_0). \tag{2}$$

The incident neutron propagates along the axis z with the energy E_0.

According Serebrov et al. (see formulae (20) in [1]) the cross-section of neutron capture by the defect is strongly enhanced, i.e.

$$\sigma_{\text{capt}}\big|_{E_0<U} = \frac{|U - E_0|}{W}\,\sigma_{\text{capt}}\big|_{E_0>U}\,,$$

for subbarrier neutrons (indeed, typically $|U - E_0|/W \sim 10^4$). This result is obviously wrong because the capture cross-section for subbarrier neutrons appears to be infinite in a trivial limit of non-absorbing medium ($W = 0$).

The scattering problem can be easily solved within the well-known distorted wave Born approximation (DWBA). This approximation is used in the situation where a potential can be presented as a sum of two parts $V = V_1 + V_2$. The Schrödinger equation for the first potential V_1 is solved exactly whereas the influence of the second potential V_2 is taken into account in first order of the perturbation theory.

The general answer for the scattering amplitude $F^{(2)}(\mathbf{k}', \mathbf{k})$ can be found in any textbook on scattering theory, for instance in [2], and has the form

$$F^{(2)}(\mathbf{k}', \mathbf{k}) = -\frac{m}{2\pi\hbar^2}\langle\Psi^{(1)-}_{\mathbf{k}'}|V_2|\Psi^{(1)+}_{\mathbf{k}}\rangle, \tag{3}$$

where $\Psi^{(1)\pm}_{\mathbf{k}}(\mathbf{r})$ are exact solutions of the Schrödinger equation for the first potential (distorted waves). The difference with the usual Born approximation is in the fact that the plane waves are replaced by exact solutions for the first potential.

Exactly the same approach can be applied to calculate the capture cross-section. In fact, the capture of the neutron by the defect implies the transition from an initial state (propagation of neutron up to capture $|i\rangle$, and $|0\rangle$ for radiation field) to a final state (captured neutron $|f\rangle$ followed by emission of γ into the state $|\gamma\rangle$). The capture cross-section is then given by the ratio of the capture rate to the density flux of the incident neutrons. Using the Fermi rule, we obtain

$$\sigma_{\text{capt}} = \frac{2\pi m}{\hbar^2 k}\sum_{f,\gamma}|\langle f, \gamma|\hat{V}|i, 0\rangle|^2, \tag{4}$$

where summation goes over all final neutron and γ states, and $\hat{V}$ is the coupling between the neutron-defect system and the radiation field.

By direct analogy with (3), formula (4) gives the capture cross section which is proportional to the squared modulus of the initial neutron wave function at the defect,

$$\sigma_{\text{capt}} = |\Psi_{\mathbf{k}}^{(1)+}(\mathbf{r}_0)|^2 \sigma^0_{\text{capt}}, \tag{5}$$

where σ^0_{capt} is the capture cross section on the isolated (in vacuum) defect. Here, only the initial state is distorted by the potential (1).

In the problem considered in [1], the neutron wave function can be easily calculated for the potential (1) and, in a particular case $E < U_0$, it has the form:

$$\Psi_{\mathbf{k}}^{(1)+}(\mathbf{r}_0) = \frac{2k}{k + i\text{æ}} e^{-\text{æ} z_0}$$

with $k = \sqrt{2mE_0/\hbar^2}$ and $\text{æ} = \sqrt{2m(U - iW - E_0)/\hbar^2} = \text{æ}' - i\text{æ}''$, the neutron momenta outside and inside the medium. Thus the capture cross section is of the form

$$\sigma_{\text{capt}}|_{E_0<U} = \frac{4k^2}{(k + \text{æ}'')^2 + \text{æ}'^2} e^{-2\text{æ}' z_0}\, \sigma^0_{\text{capt}} \simeq \frac{4E}{U} e^{-2\text{æ}' z_0}\, \sigma^0_{\text{capt}}.$$

The factor of proportionality takes the maximal value 4 at $E_0 = U$ and $z_0 = 0$. It results from coherent summation of contributions from the incident and reflected neutron waves.

For $E_0 < U$ and for realistic distances $z_0 > 0$ between the defect and the medium surface, the factor $|\Psi_{\mathbf{k}}^{(1)+}(\mathbf{r}_0)|^2$ determines suppression but not enhancement and has very simple physical interpretation. The exponential term is an attenuation of the neutron wave function in the medium. The deeper the defect inside the medium, the smaller (exponentially) this factor.

To conclude notice that the phenomena of enhancement or suppression of a process probability due to interaction in a final and/or in a initial state are very well known in physics. As example, let us cite only the case of Coulomb interaction in nuclear reactions. Coulomb interaction can suppress the cross-sections of nuclear reactions at low energies due to the repulsion between nuclei or enhance the cross-sections and change their behavior (from usual $1/v$-law to $1/v^2$-law) if the charges of strongly interacting particles are opposite (attractive Coulomb interaction) [3]. These examples illustrate perfectly the

physics of this phenomenon: an attractive “external” (long range) interaction pushes the wave function into the region of “internal” short range) interaction and thus enhances the latter cross-sections; a repulsive “external” interaction pushes the wave function out and suppresses the cross sections. Therefore no repulsive interaction (as in the case discussed in [1] with positive Fermi potential) can produce an enhancement phenomenon and explain anomalous losses of UCN.

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